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Research Article

Effect of Steaming as Postprocessing Method on Rice Flour and Jaggery 3D Printed Construct

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In this study, the 3D printing of a traditional South Indian snack, "sweet pidikollukattai" has been attempted. The mixing properties of the rice flour used and thermal characteristics of the paste (rice flour, jaggery, and water) have been reported. The traditional form of the product (control) was compared with the 3D printed product, which has been postprocessed by steaming at different time durations (S_1-5, S_2-10, S_3-15 min). A comparative evaluation of the proximate analysis, colour, weight, dimensional measurement, texture profile analysis, and sensory characteristics was done for all samples. No significant difference was observed in colour, proximate composition, weight, and dimensional variation between the 3D printed samples and the control sample. Texture profile analysis revealed that the S_2 score is comparable to the control sample. S_2 also scored higher on the sensory scale compared to other samples. It was concluded that the 3D printed sample of the recipe, steamed for 10 min, has better acceptability compared to other samples.

1. Introduction

3D food printing is an upcoming production technology that is based on layer-by-layer deposition of food material to obtain unique structures that may be difficult to obtain using traditional methods. 3D printing is also known as Food Layered Manufacture (FLM), additive manufacturing, or rapid prototyping, is the process of incorporating interactive designs, fortification of nutrients, and the immense level of customization freedom to end-users [1]. Currently, 3D food printing is still in its nascent stage, but this technology can be adopted worldwide in the backdrop of an increasing customized food production trend [2].

Numerous studies on the printing of cereal products have been reported [3, 4]. Rice (Oryza sativa), which is one of the staple food crops of the world, is widely used in various forms of food both as whole grain like in the making of biryani and various variety rice and as rice flour for making various dishes like idli, rice flour pancakes, rice flour mango mochi, and so on [5]. Many people in South and Southeast Asia use rice flour to prepare various conventional and novelty food items [6]. For the purpose of 3D printing, protein and gluten are important components that impart viscoelastic behaviour to the food. Since rice is low in protein and gluten, it does not lie in the natively printable category [5]. In such cases, some additives are usually added to improve the printability of rice flour [5, 7, 8]. In this study, rice flour has been mixed with jaggery and water, which led to an improvement in the viscoelastic properties of the paste, making it suitable for 3D printing [9]. Jaggery can be used as a healthy alternative to sugar in 3D food printing [10]. However, the texture of the final product can be further improved by supplementary processing steps.

Postprocessing can result in beneficial changes in the texture and can make the final product readily consumable. The most commonly used postprocessing method used for 3D printed products are baking, frying, steaming, and occasionally, lyophilisation. As one of the healthiest cooking techniques, steaming has been commonly used for both household and industrial food processing [11]. However, heat transfer in porous starchy foods is more complicated because of the evaporation-condensation mechanism. Therefore, the cooking times must be carefully controlled in steam cooking in order to avoid undercooking or overcooking of the product [12]. The data on postprocessing of 3D printed products is extremely limited, which poses a greater challenge to the consumer acceptability of final 3D printed products [13].

Sweet pidikolukattai is one of the South Indian sweet dishes which use rice flour and jaggery to form a paste while its characteristic shape is given manually in a traditional way [14]. Significant efforts have been made in 3D printing of this product by the current research group by optimizing the paste combination [9] and printer parameters, previously. The optimized combination of the ingredients for 3D printing and optimized printer parameters have been used in this study. This will be one of the important steps in bringing the traditional recipes to the concept of 3D printing without the supplementation of any extra additives.

The aim of this work is to investigate the effect of steaming time as a postprocessing method for 3D printed sweet pidikolukattai and its comparison with traditionally made counterpart on characterization and sensory basis. The raw paste has been characterized (mixing properties and thermal characteristics) and physicochemical characterization (proximate, colour, weight, and dimensional measurement) of the postprocessed samples have also been done along with sensory and texture profile analysis.

2. Materials and Methods

2.1. Paste Preparation. The raw materials used in this study were rice flour, jaggery, and water. The paste used in the experiments was produced by the method enumerated by Thangalakshmi et al. [9]. Rice grains were cleaned, washed, sun-dried, milled, and sieved through a 250-micron sieve. Jaggery was purchased from 24 Mantra (G-Sresta Natural Bioproducts, India).

Distilled water was used for sample preparation. Briefly, 114.93 g of water was heated along with 33.04 g of jaggery up to 75°C. This mixture was then, added to 85.95 g of rice flour and thoroughly mixed. The resulting paste was then cooled to room temperature and taken for printing, followed by formal analysis.

2.2. Paste Characterization

2.2.1. Mixing Properties. The Brabender Farinograph (C. W. Brabender Instruments, Inc., South Hackensack, NJ, USA) was used for the measurement of water absorption values and peak mixing time of the rice flour [15]. This was done as described in AACC 54–21, 2000. In this method, the requisite amount of distilled water was added to 300 g of the sample to reach 500 BU and the required farinograph profile was collected as per the protocol suggested by Hussain et al. [16].

2.2.2. Thermal Properties of Paste. The thermal characteristics were studied using differential scanning calorimetry (DSC) (Model 200F3A01, Netzsch, China) previously calibrated with indium. About a 5 mg sample was weighed in an aluminum pan and hermetically sealed.

Samples were heated from 25 to 200°C at a constant heating rate of $10^{\circ}C\,min^{-1}$. An empty aluminum pan was used as a reference. Temperature (T_o-onset, T_p-peak, T_e-end) and enthalpy of the thermal transitions (ΔH, $J\,g^{-1}$) were calculated using associated software [17].

2.3. 3D Printing Experiments. ZMorphVx multitool 3D printer was used for 3D printing experiments using its thick paste extruder. The syringe has a capacity of 100 ml. The prepared paste was filled into the syringe, and necessary precautions were taken so that no air entrapment occured while filling the syringe with the paste. Figure 1 shows the experimental plan of the entire process and the target geometry for printing. The printer parameters were previously optimized by the research group (nozzle diameter ND: 1.5 mm, layer height LH: 29% of ND, pathwidth (PW): 0.753, and print speed: 20 mm/s). The other standard parameters set included the layer count (LC) = 15 and travel speed = 120 mm/s. The printing was carried out on food grade SS mesh, so that the image once printed can be transferred into the steamer without disturbing the shape. The image was fed to the printer using voxelizer software. The generated g-codes were then run to carry out the printing experiments.

2.4. Postprocessing. The traditional South Indian sweet dish of "sweet pidikolukattai" was prepared from the same dough by hand pressing method and steamed for 10 minutes and was considered as the control sample (C) [14]. The 3D printed product was subjected to 3 different steaming times of 5, 10, and 15 minutes which were labelled as S_1, S_2, and S_3, respectively.

2.5. Effect of Postprocessing

2.5.1. Proximate Analysis. The moisture, protein, carbohydrate, fat and ash content of the postprocessed 3D-printed samples and control were analyzed according to standard AOAC methods [18].

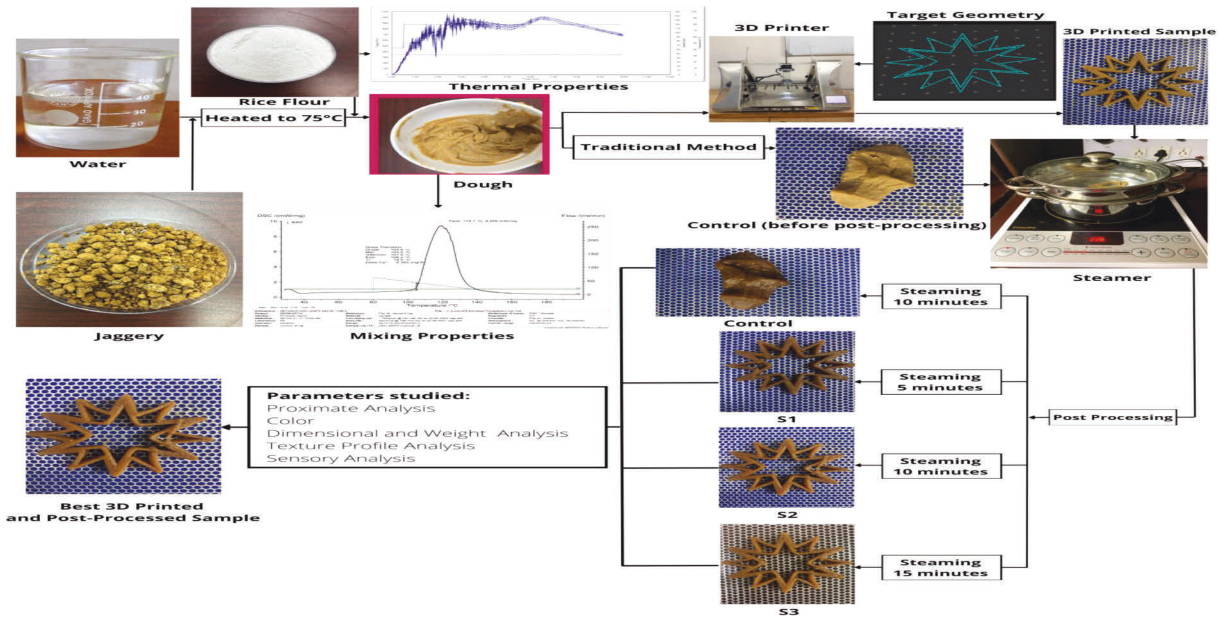


Figure 1: Experimental plan adapted for this investigation and the target geometry.

2.5.2. Colour. The colour characteristics of the control and samples S_1, S_2, S_3 were analyzed using Colour Flex EZ (Hunter Lab, USA) in terms of luminosity (L^*), redness index (a^*), and yellowness index (b^*) after calibration with a jet black plate and a white plate [18]. The colour differences between samples were calculated by comparing with the unprocessed 3D-printed samples, using the following equation:

$$\Delta E = \sqrt{(L_c^* - L_i^*)^2 + (a_c^* - a_i^*) + (b_c^* - b_i^*)}, \quad (1)$$

where L_c^*, a_c^* and b_c^* refers to values of control samples and L_i^*, a_i^* and b_i^* refers to the colour values of 3D printed samples S_1, S_2, and S_3.

2.5.3. Weight and Dimensional Measurement. The weight of the samples before and after processing was measured using a weighing balance (accuracy of ±0.1 g). The diameter and height of the 3D printed samples were measured before and after postprocessing to determine the effect of postprocessing on dimensional accuracy using a digital vernier caliper (Mitutoyo Absolute, Japan).

2.5.4. Texture Analysis. Textural profile analysis was performed using a texture profile analyzer (TA-HD Plus, Stable Microsystems Ltd. UK) with a stainless-steel cylindrical probe P10 (10 mm diameter) equipped with a 30 kg load cell. The analysis was set for two compression cycles. The test conditions were set as follows: pretest speed: 1 mm/s, test speed: 1 mm/s, posttest speed: 1 mm/s and strain 75%, trigger force 5 g and pause between two compressions of 1 s [10]. Hardness, adhesiveness, springiness, cohesiveness, chewiness, and resilience were estimated.

2.5.5. Sensory Evaluation. Sensory evaluation was carried out using twenty-five semitrained panellists (students and faculty members of National Institute of Food Technology Entrepreneurship and Management, Kundli, Sonepat, Haryana, India). Samples were scored for appearance, taste, texture, and overall acceptability on a 9-point hedonic scale with 1 representing 'dislike extremely', 5 representing 'neither like nor dislike' and 9 representing 'like extremely' [19].

2.5.6. Statistical Analysis. Data was expressed as mean ± standard deviation and analyzed with Duncan's multiple range test to evaluate the significant difference ($p \leq 0.05$) among groups. The statistical analysis was done with the GLM (General Linear Model) procedure using SPSS 25.0 (SPSS Inc., Chicago, IL, USA) statistical software.

3. Results and Discussion

3.1. Material Characterization. The mixing properties of the rice flour have been shown in Table 1. The water absorption was 77.8%. The rice flour particles went inside the gap between the mixing bowl and the mixer blade of the Farinograph, resulting in an increased torque towards the end of the measurement.

The dough development time of 6.6 min is in the range defined for different rice and wheat flour blends reported by [20] ranging from 3.3 min to 7.3 min. The stability time was found to be 0.9 min, which is closer to the reported value for rice flour blends of 1 min [21]. The water absorption percentage reported for rice flour was 57.5% [15] in contrast to the value obtained in our experiments of 77.8%. This

Table 1: Mixing and thermal characteristics of flour and paste.

Mixing properties of rice flour		Thermal characteristics of paste	
Stability time (min)	0.9	T_o (Onset temp. of gelatinization) (°C)	104.8
Development time (min)	6.6	T_p (Mid temp.) (°C)	104.9
Maximum torque (FU)	973.4	T_c (End temp.) (°C)	106.2
Water absorption (%)	77.8	H (Enthalpy) (J/g.K)	6.383

Table 2: Proximate and colour data of the samples.

Samples	Proximate data					Colour values			
	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Carbohydrate (%)	L^*	a^*	b^*	ΔE
Control	63.21 ± 2.13^a	0.43 ± 0.01^a	2.09 ± 0.23^a	0.48 ± 0.02^a	33.79 ± 1.23^a	38.45 ± 1.23^b	3.54 ± 0.23^a	6.38 ± 0.54^b	-
S_1	60.61 ± 1.21^a	0.44 ± 0.01^a	2.15 ± 0.13^a	0.49 ± 0.01^a	36.31 ± 2.12^a	33.92 ± 2.34^a	3.89 ± 0.43^a	9.23 ± 0.67^d	5.56 ± 0.56^b
S_2	61.12 ± 1.34^a	0.44 ± 0.08^a	2.14 ± 0.15^a	0.49 ± 0.00^a	35.81 ± 2.22^a	37.81 ± 2.13^b	3.69 ± 0.23^a	7.13 ± 0.67^c	1.08 ± 0.13^a
S_3	61.14 ± 1.21^a	0.44 ± 0.09^a	2.13 ± 0.09^a	0.48 ± 0.01^a	35.81 ± 2.65^a	39.05 ± 1.65^b	3.52 ± 0.32^a	5.59 ± 0.43^a	1.30 ± 0.04^a

difference may be due to the varietal difference in rice or a difference in particle size.

The gelatinization temperature of the rice flour and jaggery paste was determined to be 104.8°C. The gelatinization temperature determined for different varieties of rice flour by [6] was 70.07 to 79.39°C. The increase in the gelatinization temperature of our paste may be attributed, to the presence of jaggery in the printable paste.

It has been reported by [22] that the delay in gelatinization temperature of starch in the presence of sugar is due to the antiplasticization effect of sugar water cosolvents as compared to water alone. The maximum increase of starch granules during swelling is usually reached at 75°C [23]. This temperature was reached during the preparation of the paste. Hence, it is expected that the starch granules present in rice flour has reached maximum swelling during the paste preparation stage.

3.2. *Effect of Postprocessing Colour and Proximate Composition*

3.2.1. Proximate Analysis. The results of proximate analysis are presented in Table 2. On an average, a variation of 3.5% is observed in the moisture content between the control and 3D printed samples, although the variation is found to be insignificant. Due to the relatively open structure, vapour diffusion through the surface during the steaming process is accessible [11]. There is no significant difference in values of ash, protein, fat, and carbohydrate % of the samples since the basic ingredients are the same and steam timing does not impact these values significantly.

3.2.2. Colour. The measured colour parameters are presented in the table. The lightness value of L^* had no significant difference between control, S_2 and S_3. Only S_1 had a lower lightness value than the other samples since cooking was done for lower time duration. a^* value had no significant difference between all the samples. The brownness value b^* varied significantly among the samples may be due to the reason that the sample was basically brown in colour due to jaggery and the different timing of steaming gave a bit different tint of brown colour. The colour change ΔE did not vary significantly between S_2 and S_3. The 3D printing does not introduce any significant variation in colour.

3.2.3. Weight and Dimensional Measurement. The weight and dimensional measurements of the samples are presented in Table 3. The weight gain % of the sample was maximum in case of control sample (8.16%) and there was no significant difference in weight gain between the samples. The weight gain in samples is due to the addition of moisture due to steaming [3]. It can also be observed that the moisture percentage is maximum in the case of the control sample, and hence the weight gain is also maximum for the control sample which shows that the weight gain is due to the addition of moisture in the sample during steaming.

The diameter and height of the sample decreased after steaming. The rate of decrease in height was proportional to the time of exposure to steam, with the maximum change noted for the S_3 sample having 15 minutes of steaming, though the change was not significant [5] have also reported that the height of the steamed 3D printed rice products has been reduced.

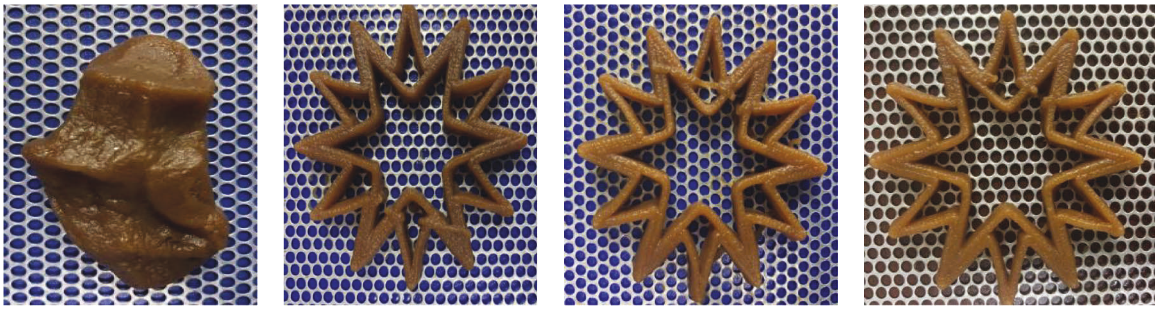
3.2.4. Texture Profile Analysis. The results of the texture analysis are presented in Table 4. Sample S_1 had the lowest hardness value of all the other samples, this may be attributed to the fact that undercooking of the sample occurred due to lower steaming time. Sample S_3 had the highest hardness value of all the other samples, which may be due to longer cooking time. There was a nonsignificant difference in the hardness of the control and S_2 samples. The adhesiveness is found to be significantly higher for control samples compared to all 3D printed samples. Adhesiveness is the work required to overcome the attractive forces between the surface of the food and the other surface with which the food comes into contact [9]. This force is found to be higher for the control sample since it may be one whole unit, whereas in the 3D printed sample, it is a congregation of different layers, which reduces the amount of integrity within the sample, and hence, adhesiveness is significantly less in all the 3D printed samples compared to the control

Table 3: Weight and dimensional data of the samples.

Samples	Weight before processing	Weight after processing	Gain in weight	% Gain in weight	Diameter before processing	Diameter after processing	Change in diameter	Height before processing	Height after processing	Reduction in height
Control	20.2 ± 1.02^{b}	21.63 ± 1.23^{b}	1.65 ± 0.05^{a}	8.16 ± 0.71^{a}	—	—	—	—	—	—
S_1	19.76 ± 1.76^{b}	20.8 ± 1.23^{ab}	1.1 ± 0.01^{a}	5.50 ± 0.45^{b}	68.25 ± 1.23^{a}	67.78 ± 1.23^{a}	0.66 ± 0.04^{b}	8.75 ± 0.34^{a}	8.29 ± 0.34^{b}	0.43 ± 0.02^{a}
S_2	19.76 ± 0.91^{b}	20.9 ± 1.67^{ab}	1.2 ± 0.02^{a}	6.00 ± 0.54^{c}	68.74 ± 1.23^{a}	68.50 ± 2.43^{a}	0.31 ± 0.03^{a}	8.78 ± 0.23^{a}	8.24 ± 0.65^{b}	0.42 ± 0.03^{a}
S_3	18.86 ± 1.23^{a}	20.06 ± 1.23^{a}	1.15 ± 0.03^{a}	6.09 ± 0.51^{c}	68.6 ± 2.34^{a}	68.56 ± 1.43^{a}	0.06 ± 0.00^{a}	8.56 ± 0.32^{a}	7.91 ± 0.54^{a}	0.53 ± 0.04^{b}

Table 4: Texture profile analysis and sensory score of samples.

	Texture profile analysis							Sensory score			
	Hardness, (g–f)	Adhesiveness (g-sec)	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience	Appearance	Taste	Texture	Overall acceptability
Control	1095.45 ± 12.3^{b}	-313.55 ± 4.23^{a}	0.37 ± 0.02^{b}	0.29 ± 0.01^{b}	320.44 ± 2.98^{c}	152.14 ± 9.12^{c}	0.11 ± 0.00^{b}	5.33 ± 0.5^{a}	7.33 ± 0.45^{a}	6.66 ± 0.56^{ab}	6 ± 0.34^{a}
S_1	881.32 ± 6.87^{a}	-69.9 ± 3.76^{b}	0.26 ± 0.01^{a}	0.07 ± 0.00^{a}	66.9 ± 3.45^{a}	18.53 ± 1.12^{a}	0.01 ± 0.00^{a}	8 ± 0.91^{b}	6.33 ± 0.71^{a}	5.66 ± 0.43^{a}	6.33 ± 0.74^{a}
S_2	1018.05 ± 4.56^{b}	-83.45 ± 7.56^{b}	0.27 ± 0.03^{a}	0.07 ± 0.00^{a}	77.32 ± 5.67^{a}	21.58 ± 1.56^{a}	0.01 ± 0.00^{a}	8.66 ± 0.55^{b}	7.33 ± 0.65^{a}	7.66 ± 0.65^{b}	8 ± 0.76^{c}
S_3	1404.78 ± 12.54^{c}	-97.57 ± 6.56^{b}	0.26 ± 0.01^{a}	0.08 ± 0.00^{a}	123.77 ± 7.87^{b}	32.58 ± 2.7^{b}	0.02 ± 0.00^{a}	7.66 ± 0.65^{b}	7.33 ± 0.83^{a}	6.67 ± 0.75^{ab}	7.33 ± 0.76^{ab}



(a) (b) (c) (d)

FIGURE 2: Sample images of (a) Control (b) S_1 (c) S_2 (d) S_3.

sample. The other texture parameters of springiness, cohesiveness, gumminess, chewiness, and resilience were found to be higher for the control sample, may be for the reason mentioned above. Since 3D printed products are present layer wise, they may not stick with one another layer to the extent of a single entity and also there may be air entrapment between the layers. Another trend observed was the increase in hardness, gumminess, and chewiness with an increase in steaming time, and a similar trend was reported by [24] for steamed rice cakes. Hardness, which is one important factor for the product, was comparable for the control sample and S_2 sample.

3.2.5. Sensory Analysis. Since sensory analysis is one of the main methods to determine the acceptability of a product, all the 4 samples (control and 3D printed samples S_1, S_2, S_3) were subjected to sensory analysis and the results of sensory evaluation are presented in Table 4. Based on the sensory score, S_2 is found to be the optimized postprocessed sample. In appearance, all the 3D printed samples scored better than the control sample. There was no significant difference in the score on appearance among the 3D printed samples. There was no significant change in the taste scores of all the samples as the base paste was the same for all samples. It was intimated by the panellists that sample S_1 had a raw taste, may be because 5 minutes was not sufficient to fully cook the sample. Sample S_2 scored highly on all parameters of the sensory test. The overall acceptability score of S_2 was the highest of all the sample score. Hence, on a sensory basis, sample S_2 can be regarded as the optimized sample. The images of the samples presented for sensory evaluation are depicted in Figure 2.

Hence, based on TPA results and sensory score, S_2 is taken as the best postprocessed sample. Hence a steaming time of 10 minutes yields the optimized postprocessed 3D printed sample comparable to the control sample.

4. Conclusions

3D food printing of "sweet pidikollukattai" along with postprocessing i.e., steaming, was attempted in this study with previously optimized formulation and processing parameters. The 3D printed samples were steamed for 5, 10 and 15 mins, and the results were compared with the control sample. It is concluded that the 3D printed sample steamed for 10 minutes (S_2) showed similar characteristics to the traditionally prepared control sample in terms of texture profile. Further, S_2 scored better i.e., 8 ± 0.76^{c} in overall acceptability among the other samples and control sample. There was a nonsignificant difference in terms of proximate, weight, colour, and dimensional accuracy among the control and 3D printed samples. The study concludes that it may be possible to adapt some traditional recipes like sweet pidikollukattai into 3D printable format without any modification to the recipe or supplementation of any additives. The results of this study clearly demonstrate that 3D printing can be a viable option for commercial production of sweet pidikollukattai with an acceptable level of consistency.

Data Availability

Data will be made available by the authors on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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